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SEMI-ANNUAL REPORT ON

Research in Electrohydrodynamics and
Wave-Type Magnetohydrodynamic A-C Power Generation

NASA Grant No. NsG-368

Supervised by
Professor H. H. Woodson

Massachusetts Institute of Technology
Department of Electrical Engineering
Cambridge, Massachusetts

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*Personnel involved in each project are listed directly under the project heading.

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This report summarizes research activities through July 31, 1963, on NASA Research Grant NsG-368. The work can be divided into four main projects concerned with:

1. Traveling-wave MHD A-C power generation;
2. Alternating-current MHD conduction generators;
3. Continuum feedback control of EHD and MHD systems;
4. Basic investigations of EHD surface interactions.

The nature and status of each of these projects will now be defined:

1. Traveling-Wave MHD A-C Power Generation

Personnel: H. H. Woodson, Professor
F. D. Ketterer, Instructor
R. Rowe, Research Assistant
J. Steele, Student Technician

It has been shown[1,2] that it is theoretically possible to use magnetoacoustic waves to convert the kinetic power of a flowing plasma to A-C electrical power. The theoretical generator model consists of a moving plasma, a transverse constant magnetic field, and an external traveling-wave circuit. This external circuit is used to extract alternating-current power from the plasma through coupling to magnetoacoustic waves. In order for this interaction to occur, the following conditions must be satisfied:

1. the plasma must be flowing with a velocity greater than the magnetoacoustic wave velocity;
2. the plasma electrical conductivity must be sufficiently large to permit the waves to amplify as they propagate.

A Master's thesis devoted to the theoretical aspects of this problem will be completed this summer. This analysis uses numerical methods and a digital computer to evaluate the device properties for all values of coupling between the circuit and the plasma from very weak coupling to very strong coupling. (In the past, the theoretical work has been limited to weak coupling.) The most important quantities calculated are the real power-gain per wavelength and the associated value of the load impedance, which are calculated as functions of the coupling coefficient and the velocity with which electromagnetic waves would propagate on the external circuit in the absence of a plasma. It is concluded that the generator has an infinite gain at unity coupling and zero circuit velocity, where the associated load is zero. The characteristics of the generator at intermediate values of coupling are also presented.

Doctoral research is being devoted to an experiment that has been set up to produce a plasma which will satisfy the conditions for a growing wave. The system is a homopolar device in which a constant axial magnetic field between continuous concentric electrodes interacts with a radial current to produce an azimuthal rotation of the resulting plasma. Typical values for the constants of the experiment are:

Gas:	Helium	Rotational Velocity:	10^4 m/sec
Initial Pressure:	1 mm Hg.	Conductivity:	10^3 mho/m
Magnetic Field:	4000 gauss	Plasma Duration:	100 μsec.
Current:	10,000 amps	Magnetic Field Duration:	5 msec.
Plasma Voltage:	300 volts		

Gas velocities have been obtained which are greater than the acoustic velocity, but are less than the magnetoacoustic velocity.

During operation, a localized arc is first formed which spreads out as it rotates until a diffuse plasma is formed in one or more rotations of the arc, depending predominantly on input power and magnetic field and less on the pressure. If a sufficient input power or magnetic field is not achieved no diffuse plasma is produced.

Current efforts are devoted to excitation and detection of magnetoacoustic waves in the diffuse rotating plasma. To do this, a capacitor is discharged through a pair of small electrodes in an insulated section of the channel. The disturbance is to be observed by similar pairs of electrodes downstream and by small magnetic loops immersed in the plasma.

The launch circuit and pickup electrodes are in operation with the magnetic probes being constructed.

2. Alternating Current MHD Conduction Generators

Personnel: H. H. Woodson, Professor
G. L. Wilson, Research Assistant
J. L. Miller, Student Technician
B. McGregor, Student Technician

Theoretical work has been done which predicts that it is possible to use two, properly-connected MHD conduction machines, or a properly-connected Hall-effect machine to generate alternating current, without using large external capacitors.[3,4] As a first phase of the experimental investigation of this machine, a facility has been constructed which is expected to produce the required gas conditions necessary to perform the generator experiments. (This work is the topic of a Master's thesis which will be completed this fall.) The apparatus consists of two concentric cylindrical electrodes immersed in an external axial magnetic field. (The device is similar to the one described in the previous section.) A capacitor bank is discharged between the electrodes, breaking down the gas and establishing a radial current which both heats the gas and accelerates it in the azimuthal direction. The capacitor bank is 5,800 μf at 4 kv., which is in series with a coil whose inductance is chosen to give a critically-damped circuit and thus achieve a high transfer of energy to the gas. The measured voltage and current into the gas indicate that the circuit is very nearly critically-damped and that with two kilovolts on the capacitor bank, ten megawatts of power are delivered to the plasma over a 300 μsec period of time. Preliminary photomultiplier measurements indicate that the plasma is diffuse over the 300 μsec period.

A pressure transducer and high impedance amplifier system are currently under construction. The system is designed to measure pressure pulses with rise times of down to 50 μsec. When these transducers are completed, they will be mounted in an insulated test section in the brass rings and will be used to determine the gas temperature. In addition, a set of probes are mounted in the test section in order to measure the gas velocity. These measurements are currently in progress.

3. Continuum Feedback Control of EHD and MHD Systems

Personnel: J. R. Melcher, Assistant Professor and Ford Post Doctoral Fellow
H. Atlas, Senior Technician

A considerable amount of theoretical and experimental work has been done to understand a Rayleigh-Taylor type instability induced by an electric field (EH-If).[5,6] It has been shown theoretically that it is possible to stabilize a fluid interface at electric pressures where it would normally be unstable, by introducing a continuum of position feedback.[7] An experiment has been constructed and is currently being tested which will provide a careful testing of the significance of the theory.

The apparatus is shown in Fig. 1. In equilibrium, the interface is stressed by an electric field provided by the potential V_o (fields on the order of 3×10^6 v/m which make it necessary to use a SF_6 atmosphere). The surface becomes unstable at sufficiently large values of V_o. The resulting deformation of the interface focuses or defocuses light on a grid of photocells as shown in Fig. 1, so that a signal which is proportional to the interface position is fed back to the electrodes, and made to stabilize the interface. Tests so far have been confined to testing the optical scheme. The transfer function (in terms of wave number) of each of the feedback components (detector, amplifier and electrode) are measured by exciting waves on the surface of the fluid at a known wavelength (in resonance).

In the actual experiment, four segments and four sampling points for the detector are used. Clearly this is a crude approximation to the ideal continuum of feedback assumed in the original theory. Further theoretical work is now being carried out which takes into account the

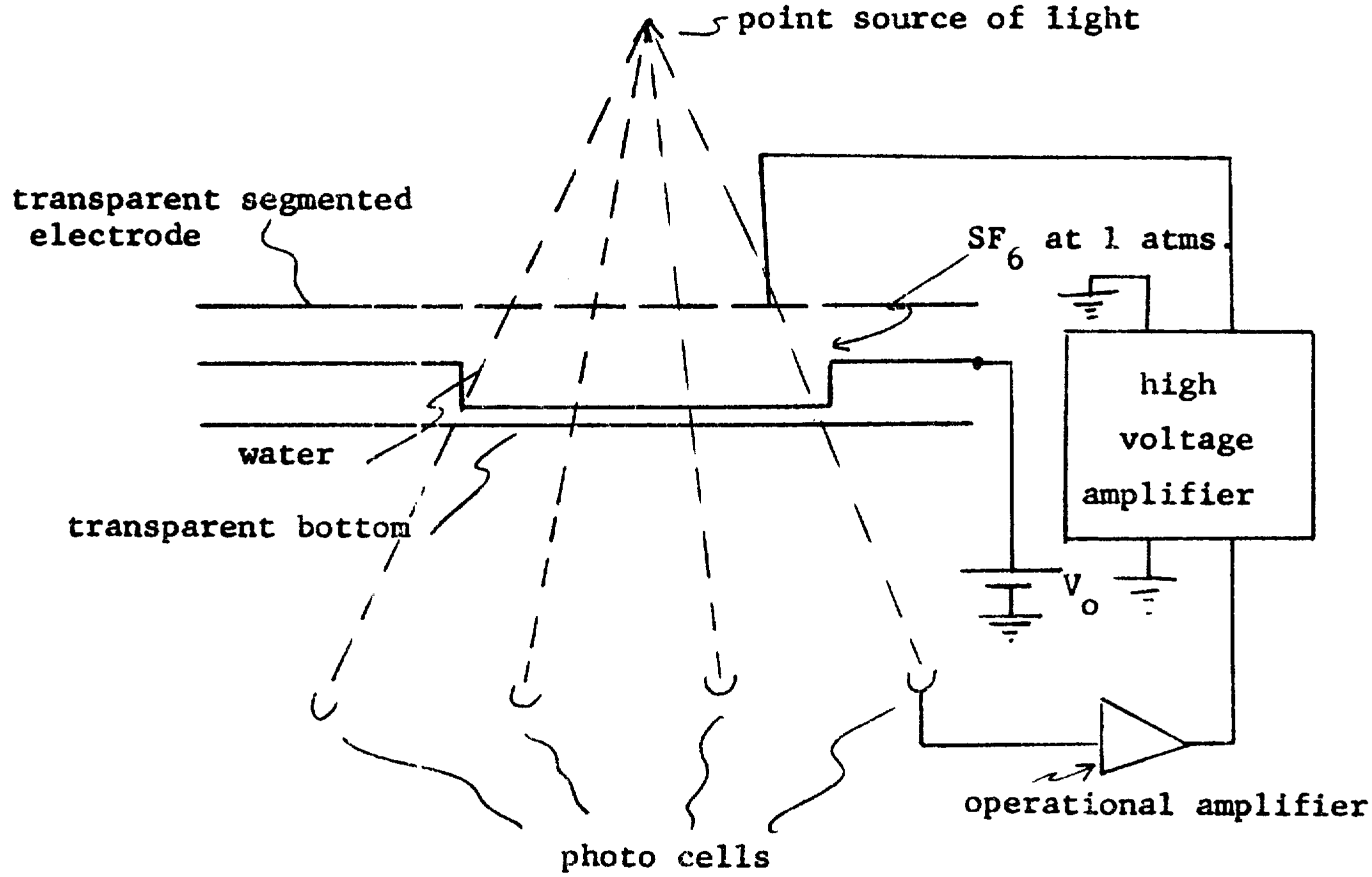

Figure 1.
Experiment for "continuum" feedback control of EH-If instability.

finite size of the electrodes and the finite number of cells. The effect is somewhat analogous to the effect produced in an ordinary feedback loop by a time-wise (rather than space-wise) sampler.

If it is found that the system can be simplified to a sufficient degree, the number of electrodes will be considerably increased on a second-generation experiment by making use of an analog computer. Eventually, it is hoped that the problem can be understood in terms of sampling in both space and time, where the data are collected at each station at finite intervals of time, much as is done by a television system. This would make it possible to use a single wide-band, high-gain amplifier instead of the "grid" of amplifiers which is presently used.

Analytical work has been done on the effect of continuum feedback on the MHD pinch. Preliminary indications are that stability can be improved, but considerable numerical work remains to be done. (Essentially, it is necessary to repeat the numerical work that went into the, now-classical analysis of the pinch with external walls, but including the effect of the feedback.)

4. Basic Investigations of EHD Surface Interactions

Personnel: J. R. Melcher, Assistant Professor and Ford Post Doctoral Fellow
J. M. Crowley, A.E.C. Fellow
H. Atlas, Senior Technician

A Master's thesis devoted to the study of the excitation and growth rate of EHD instabilities will be completed this summer. However, this work will continue through the next reporting period. Although we have previously made a detailed study of the EH-If instabilities, (convective and non-convective), no previous attempts have been made to correlate rates of growth with theoretical predictions because theoretical work did not include the effects of viscosity. An investigation that includes mechanical losses is now in progress,[8] and correlating experiments are being conducted. The objective here is to establish the role of mechanical losses in EHD surface coupled systems.

An outgrowth of this work is the effort being made to understand theoretically and experimentally the properties of various electric devices for exciting and detecting the instabilities. This work was found necessary as a basis for making meaningful measurements of absolute wave-amplitudes.

An experimental and theoretical study of centrifugal EHD waves and instabilities is now in an advanced stage. In this work we are concerned with the dynamics of an interface, stressed by an electric field (on the order of 10^7 v/m) when the fluid interface is rotating at 20-60 cps. In order to obtain fields that can compete with the rotational forces, it has been found necessary to pressurize the systems with an atmosphere of SF_6. Good experimental data on the conditions for instability are now being obtained. The theoretical dispersion relation is extremely complicated and will require considerable numerical analysis. It has been found that the rotation tends to stabilize the system, with the impending instabilities occurring at wavelengths which are on the order of 0.5 mm in length. This experiment is likely to lead to studies of systems that involve both rotation and translation of interfaces stressed by an electric field.

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